ATLAS and CMS B Physics Prospects

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- Overview of ATLAS and CMS physics studies
- CP violation studies
- B_s^0 sector
  - B_s^0 Oscillation measurements
  - $B_s^0 \to J/\phi$
- Rare decays
- Conclusions

Introduction

- ATLAS and CMS primarily conceived and optimised for high-luminosity LHC environment (physics beyond the Standard Model,Higgs searches)

- First three years of low luminosity operation will allow investigation of B physics issues influencing their design (some rare decays possible even at high luminosity)

- Expected LHC luminosity in first three years

$$\mathcal{L} \sim 10^{33} cm^{-2} s^{-1} \text{ giving } 10^{4} pb^{-1}/\text{year}$$

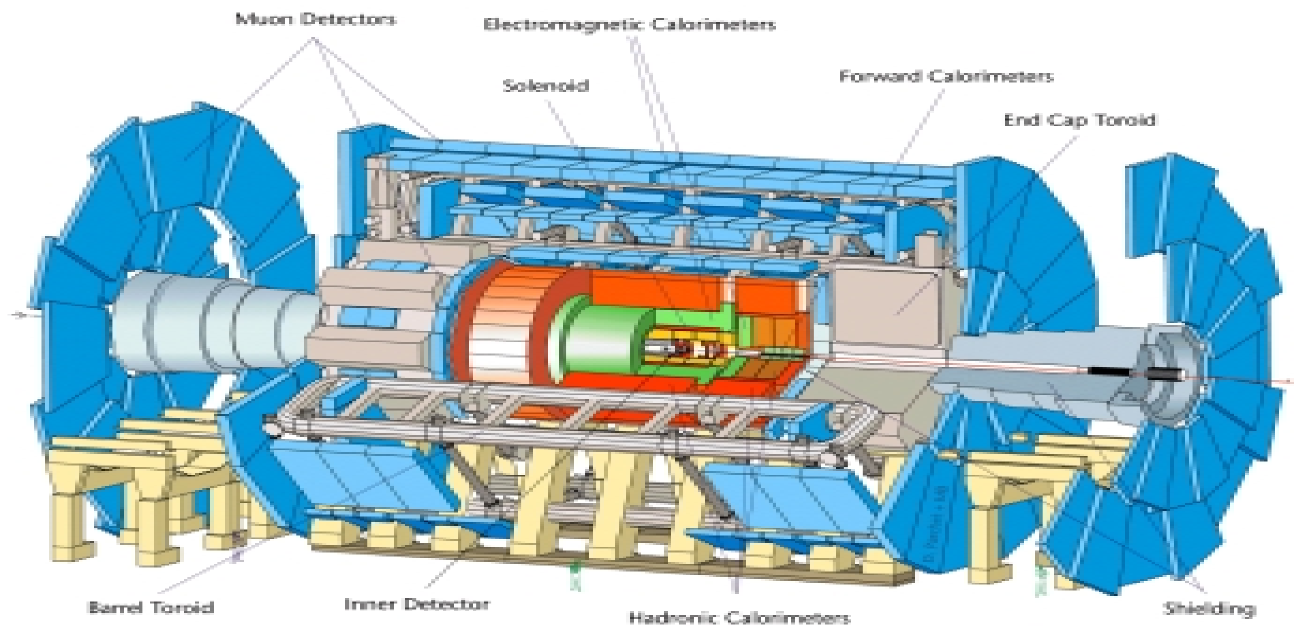
$\Rightarrow$ Expect 10^{12} $b\bar{b}$ events/year with millions fully reconstructed

- Enormous statistics and full spectrum open up rich possibilities for B physics on CMS and ATLAS

- Drawback - little or no hadron identification but can be overcome by good mass resolution in some cases (e.g. CDF)

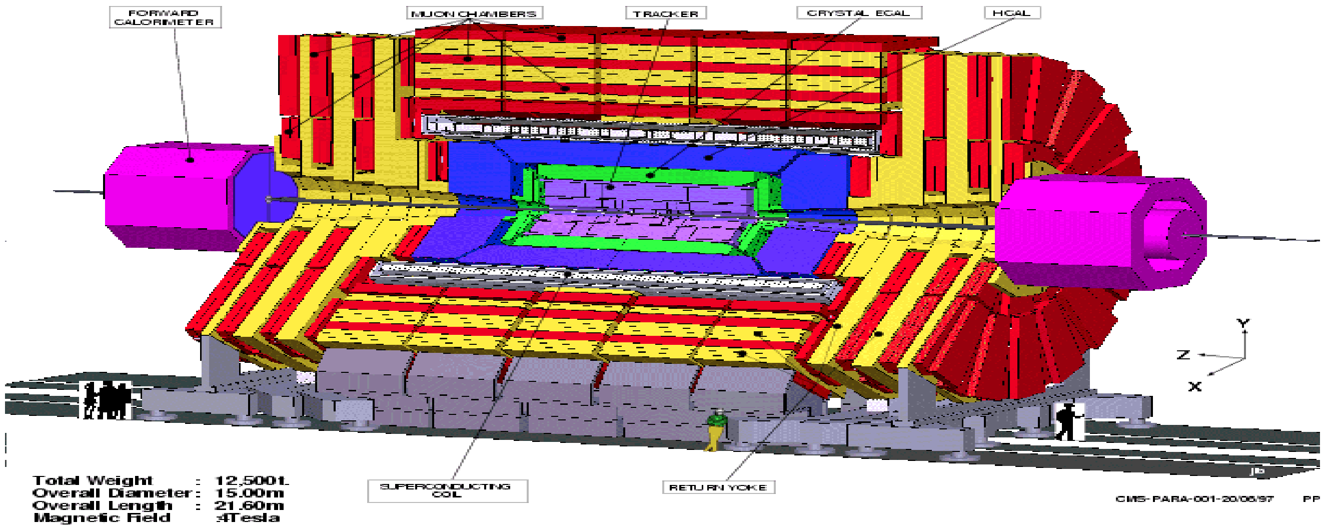
- All studies done with Pythia assuming $\sigma_{b\bar{b}} = 500\mu b$

The ATLAS Detector



- Inner detector tracking $|\eta| < 2.5$ and muon tracking $|\eta| < 2.7$
- Level 1 trigger - $p_t^\mu > 6$ GeV, $|\eta| < 2.4$
- K^0 reconstruction efficiency $\sim 75\%$ ($R < 25$ cm)
- Proper time resolution ($B_s^0 \to D_s\pi$) : 0.073 ps
- Mass resolution ($B_d^0 \to J/\psi K_s^0, J/\psi \to \mu\mu$) : 19 MeV

The CMS Detector



- Efficient μ detection upto $|\eta < 2.4$
- Level 1 trigger uses both the muons and calorimetric information with η dependent thresholds:

$$\mu > 7,\ (\mu,\mu) > 2-4,\ (\mu,e) > (2-4,7),\ (\mu,e_b) > (2-4,4),\ e/\gamma > 15,\ e_b > 10,\ (e_b,e_b) > 5$$

- Overall K^0 reconstruction efficiency $\sim 35\%$
- Proper time resolution $(B_s^0 \to D_s\pi)$: $\sim 8\%$
- Mass resolution $(B_d^0 \to J/\psi K_s^0, J/\psi \to \mu\mu)$: 20 MeV

ATLAS/CMS B Physics Programme

- What is possible for ATLAS and CMS?

Channel	Interest
$B_d \to J/\psi K_s^0$	β
$B_d \to \pi\pi$	α
$B_s \to K^+K^-$	γ
$B_s^0 \to D_s\pi$	Δm_s
$B_s^0 \to J/\psi\phi$	$\delta\gamma$
$B_{s,d} \to \mu\mu, X\mu\mu$	New Physics

- Almost all these channels very rare but not at LHC - precision measurements possible

- In addition, precision measurements of B hadrons - mass, lifetime, polarisation (B_c, Λ_b)

B factories will study B_d and B_u in detail but studies of B_c, B_s and b baryons only possible at hadron machines

Reconstructed Events with ATLAS

With three years luminosity (30 fb^{-1}), expect:

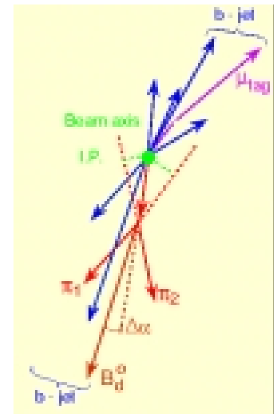
Decay mode	Branching fraction	N of events
$B_d^0 \to \pi\pi$	0.7×10^5	6500
$B_d^0 \to J/\psi K_s^0$	4.45×10^{-4}	630 000
$B_s^0 \to D_s\pi$	3.0×10^{-3}	6 800
$B_s^0 \to J/\psi\phi$	9.3×10^{-4}	300 000
$B_s^0 \to D_s a_1$	6.0×10^{-3}	3 600
$B_d^0 \to D_s a_1$	$< 2.6 \times 10^{-3}$	5 900
$\Lambda_b \to J/\psi\Lambda_0$	3.7×10^{-4}	75 000
$B_c \to J/\psi\pi$	0.2×10^{-2}	12 000
$B_c \to J/\psi\mu\nu$	0.2×10^{-2}	300 000(inclusive)

Similar statistics in CMS

Flavour Tagging

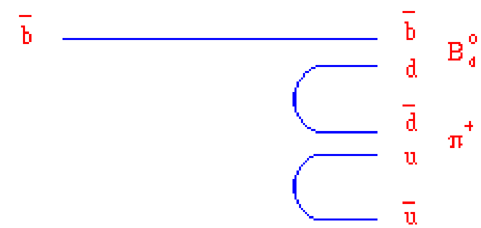
Knowledge of hadron flavour at birth necessary for most CP violation measurements

- Opposite side lepton tag:



	ATLAS	CMS
Efficiency	$\sim 4\%(e+\mu)$	$\sim 4\%$
D	$\sim 0.52(\mu), 0.46(e)$	0.44

- Same side pion(B^{**}+fragmentation):



	ATLAS	CMS
Efficiency	$\sim 82\%(\mu6,\mu3), 80\%(e,e)$	$\sim 21\%$
D	$\sim 0.16(\mu6,\mu3), 0.14(e,e)$	0.32

- Jet charge - same(ATLAS) and opposite(CMS) side:

	ATLAS	CMS
Efficiency	$\sim 64\%(\mu6,\mu3), 71\%(e,e)$	$\sim 56\%$
D	$\sim 0.12(\mu6,\mu3), 0.12(e,e)$	0.16

- Results comparable to CDF

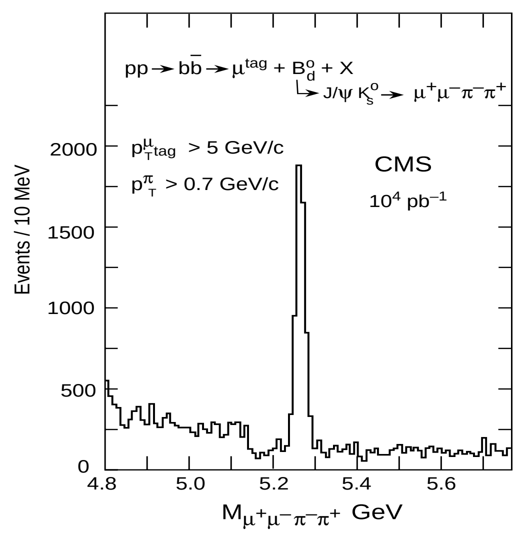
$B_d^0 \to J/\psi K_s^0$

- $\sin 2\beta$ from $B_d^0 \to J/\psi K_s^0$ is 'gold plated' CP violation channel
- Excellent measurements expected from $\Upsilon(4S)$ and Tevatron

$$\to \sigma_{\sin 2\beta} < 0.05 \text{ by } 2005$$

- LHC statistics will allow for true precision measurement
- Events in 1 year:

	ATLAS	CMS
Lepton tag	11 K	27K
B^{**} tag	134 K	22K



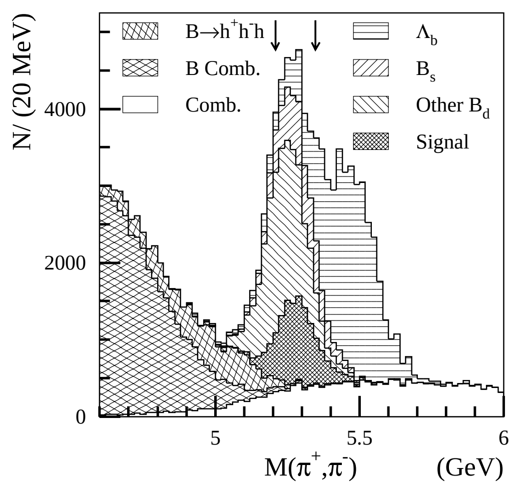
	ATLAS	CMS
Sensitivity	0.017	0.018

$B_d^0 \rightarrow \pi\pi$

- Traditionally CP asymmetry in this channel seen as primary method to measure $\sin 2\alpha$
- However, B factories will be hampered by low branching ratio ($\sim 10^{-5}$) $\rightarrow$ <1000 events total by 2005
- Much better prospects at LHC - assuming 0.7×10^{-5}:

	ATLAS	CMS
N_{evt}/year	2.2K	1.7K

- Two body background with own CP asymmetry a problem.



- ATLAS use dE/dx info, proper time, event flavour and invariant mass to reconstruct event by event likelihood fit
- Fit CP asymmetries for signal and backgound to obtain $\delta(\alpha) \sim 2^\circ$ (CMS sensitivity $\delta(\alpha) \sim 3^\circ$)
- Theoretical uncertainties?

B_s^0 *Oscillation*

- B_s^0 physics the 'Eldorado' of LHC era
- In the Standard Model:

$$\frac{\Delta m_{B_s^0}}{\Delta m_{B_d^0}} = \frac{m_{B_s^0}}{m_{B_d^0}} \frac{\eta_s}{\eta_d} \frac{F_s}{F_d} \frac{|V_{ts}|^2}{|V_{td}|^2}$$

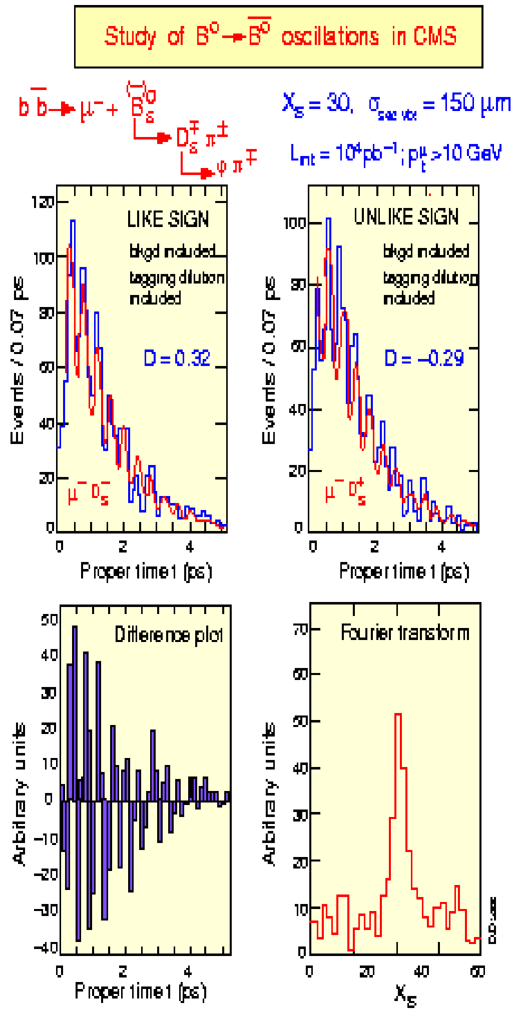
- $\frac{\Delta\Gamma_s}{\Delta m_{B_s^0}} = (5.6 \pm 2.6) \times 10^{-3} \longrightarrow$ from a direct measurement of $\Delta\Gamma_{B_s^0}$ indirect information on $\Delta m_{B_s^0}$ can be obtained
- The two measurements are complimetary - higher $\Delta m_{B_s^0}$ more difficult to measure but easier to measure $\Delta\Gamma_s$
- Mixing in $B_s^0 - \bar{B}_s^0$ system studied through time-dependent asymmetry between B_s^0 at time $t = 0$ that have oscillated(R_-) or not(R_+) to $\bar{B}_s^0$ at time t:

$$A = \frac{R_+(t) - R_-(t)}{R_+(t) + R_-(t)}$$

- $\Delta m_{B_s^0}$ is 2π times the oscillation frequency
- Best channels are exclusive flavour specific final states(like $B_s^0 \rightarrow D_s^- \pi^+$)
- Asymmetry given by:

$$A = \frac{\cos \Delta m_{B_s^0} t}{cosh \frac{\Delta\Gamma_s}{2} t}$$

B_s^0 *Oscillation Sensitivity*



Δm_s observation potential in one year:

	ATLAS	CMS
Proper time resolution	50 fs(60%), 93 fs(40%)	65 fs
5σ measurement upto	30 ps^{-1}	22 ps^{-1}
95% C.L. exclusion		31 ps^{-1}

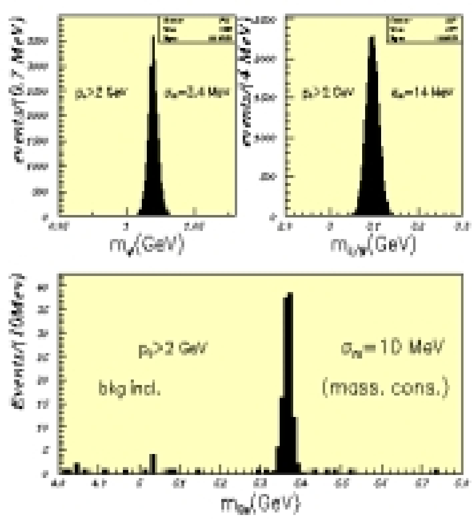
❖ Adding more channels will further improve the sensitivity

$B_s^0 \to J/\psi\phi$

- Only a small CP asymmetry predicted in the Standard Model (sizeable effect will be a clear signal of new physics) - measurement marginal

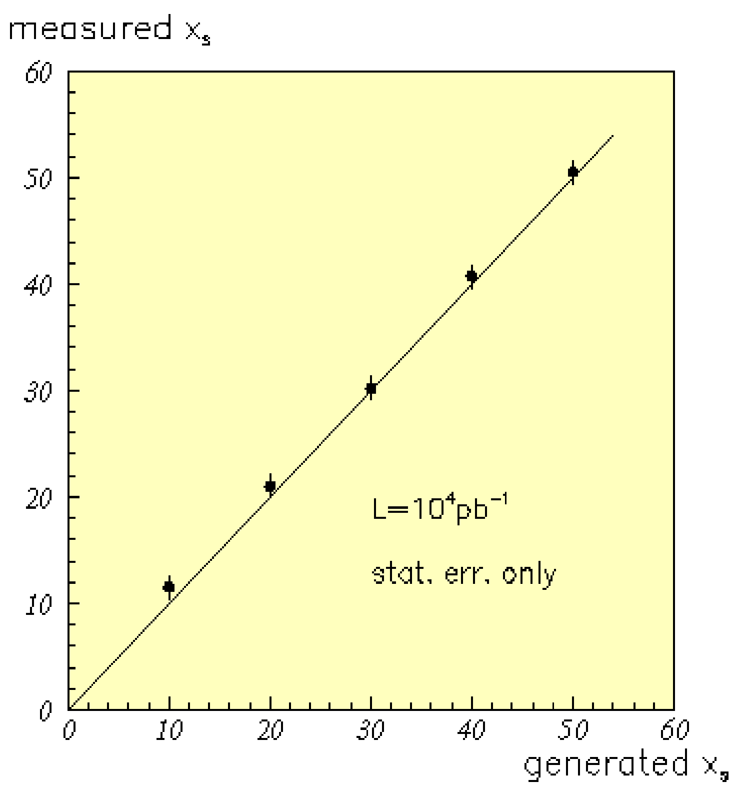
- Can be used various studies:
  - $\Delta\Gamma_s = \Gamma_H - \Gamma_L$, the difference in the width of CP-even (B_s^L) and CP-odd (B_s^H) - can be 20% of average width $\Gamma_s = (\Gamma_H - \Gamma_L)/2$
  - Two independent CP amplitudes - $A_{||}$ and $A_{\perp}$
  - The strong phase differences δ_2, δ_1
  - The weak phase difference ζ
  - The B_s^0 mixing parameter $x_s = \Delta m_s/\Gamma_s$

	ATLAS	CMS
N_{evt} (1 year)	$\sim 10^5$	$\sim 1.5 \times 10^5$
B_s^0 mass resolution(MeV)	27	10
Proper time resolution(fs)	63	68
B/(S+B)	~ 0.13	~ 0.01



$\Delta m_{B_s^0}$ *from* $B_s^0 \to J/\psi\phi$ *(CMS)*

- $\Delta m_{B_s^0}$ deduced by a $\Delta\Gamma_{B_s^0}$ measurement
- $\Delta\Gamma_{B_s^0}$ measured from untagged samples of $B_s^0 \to J/\psi\phi$ decays
  - CP eigenstates are separated and their lifetimes measured
- Possible to measure x_s up to 50 and even beyond
  - Good agreement between generated and measured x_s
  - No degradation at high x_s



Rare Decays $B^0_{d,s} \to \mu\mu(X)$

- Rare leptonic and semileptonic decays sensitive to new physics $\to$ may give indications in the first year(s) of LHC running

	SM BR	Current Limit(CDF)
$B^0_d \to \mu\mu K^{*0}$	$\sim 10^{-6}$	$< 2.5 \times 10^{-5}$
$B^0_d \to \mu\mu\rho$	$\sim 10^{-7}$	
$B^0_d \to \mu\mu\phi$	$\sim 10^{-6}$	$< 2.5 \times 10^{-5}$
$B^0_s \to \mu\mu$	$\sim 10^{-9}$	$< 2.0 \times 10^{-6}$
$B^0_d \to \mu\mu$	$\sim 10^{-10}$	$< 6.8 \times 10^{-7}$

- Possibilities to measure branching ratios, $|V_{td}|/V_{ts}|$, influence of form factors on braching ratios and dynamics of decays

- Expected number of events in three years:

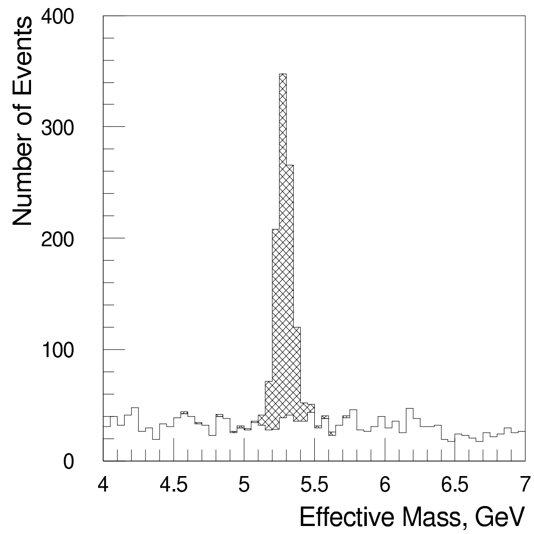
	ATLAS	CMS
$B^0_d \to \mu\mu$	4(93)	1.1(0.7)
$B^0_s \to \mu\mu$	27(93)	21(≤ 3)
$B^0_d \to \mu\mu\rho$	220(950)	350(340)
$B^0_d \to \mu\mu\phi$	410(140)	1200(70)
$B^0_d \to \mu\mu K^{*0}$	2000(290)	4200(435)

- Possible to search for purely muonic decays at high luminosity - expectations in 1 year:

	ATLAS	CMS
$B^0_d \to \mu\mu$	14(660)	
$B^0_s \to \mu\mu$	92(660)	26(≤ 6.4)

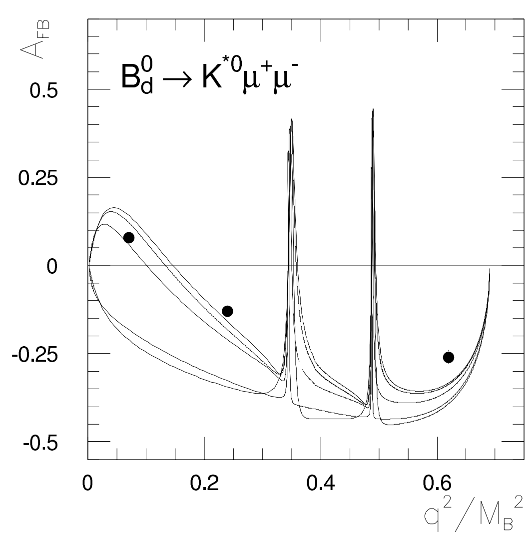
$B^0_{d,s} \to \mu\mu X$ (ATLAS)

- $B^0_d \to K^{*0}\mu\mu$ mass reconstruction with three years run:



- Forward-backward asymmetry sensitive to meson transition form factors

- Sensitivity of A_{FB} to Wilson coefficients:



- Possible to measure A_{FB} with 5% and $|V_td|/|V_{ts}|$ with 14% accuracy

Conclusions

- Thanks to their good mass and proper time resolutions, ATLAS and CMS offer enormous potential for B physics
- B physics programme complimentary to B factories (B_s^0, B_c, b baryons, rare decays)
- Some measurements competitive with dedicated B physics experiments

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